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Visual Attention and Driving Behaviors Among Community-Living Older Persons

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Background. Older drivers have higher rates of crashes per mile driven compared with most other drivers, and these crashes result in greater morbidity and mortality. Various aspects of cognition, particularly visual attention, have been linked with crash risk among older individuals. The current study was designed to specify those cognitive variables associated with specific on-road driving behaviors in a sample of older, nonclinic-referred individuals.

Methods. 35 community-residing active drivers aged 72 years and older ($M = 80$) underwent a standardized, on-road driving evaluation involving parking lot maneuvers, and urban, suburban, and highway driving. They were also administered tests of visual attention, executive function, visuospatial cognition, and memory.

Results. Driving score was significantly correlated with visual attention, visual memory, and executive function. Visual attention was associated with 25 of 36 driving behaviors, including those involving scanning the environment, interaction with traffic or pedestrians, and distance judgments. Executive function and visual memory were associated with fewer maneuvers, most of which were a subset of maneuvers that correlated with visual attention.

Conclusions. Visual attention, a cognitive function involving search, selection, and switching, plays an important role in driving risk among older drivers. In the current study, key driving maneuvers involving interaction with other vehicles/pedestrians, such as yielding right of way and negotiating safe turns or merges, have the greatest association with visual attention. Specification of both the cognitive risk factors and their impact on problematic driving maneuvers may provide guidelines for developing targeted interventions to reduce risk among older adults.

OLDER drivers have a higher incidence of crashes per mile driven than all but the youngest drivers, and they experience two to four times the risk of injury, hospitalization, and death because of these crashes (1,2). Based on the projected 50% increase in the number of older drivers by the year 2020 (3), the personal and public safety problems of crash risk among older drivers will become magnified in the next several years as the American population ages.

Recent efforts have been made to identify the individual at risk for driving impairment by specifying the factors that contribute to driving ability and driving safety among older drivers (4–10). In our own research, we have identified several functional—and potentially remediable—factors associated with history of crashes among nonclinical community-residing individuals (6). These factors have included aspects of vision (e.g., acuity, contrast sensitivity, visual fields), physical function (e.g., neck range of motion, physical mobility), and cognitive function.

Within the cognitive domain, visual attention (requiring visual search, selective attention, and switching attention) emerged as an important predictor of driving risk, as it was associated with a three-fold increased risk of crashes and/or moving violations (RR 3.0; 95% CI 1.1, 7.7) independent of vision and physical function in our sample of nonclinic-referred drivers. Other researchers have similarly shown associations between driving risk and tests of cognitive function among either nonreferred or clinic-based populations. For example, Owsley, Ball, and colleagues have conducted several studies measuring the useful field of view (UFOV) among older referred and nonreferred drivers (4,9,10). The UFOV is a measure of visual attention defined as the visual field extent needed for a visual task. UFOV was significantly correlated with crash rates in these populations. Odenheimer reported that memory tasks and an executive function task (Trail Making Test Part B) were related to driving ability in a mixed sample of normal and demented adults (8), and Lesikar and colleagues found tests of attention, visual information processing, and spatial orientation to be associated with increased risk of self-reported crashes at 2-year follow-up among older primary care patients (11). Numerous other studies have examined risk specific to drivers with known cognitive impairment, such as that due to Alzheimer's disease or traumatic brain injury, with general findings that greater overall cognitive impairment is associated with worse driving outcomes (12–14). Outcomes in these studies have included report of crashes, on-road driving performance, or simulated driving skill.

Converging evidence from our own work and that of others suggests that various aspects of cognition, in particular visual attention, are uniquely related to driving ability and driving safety among nonreferred populations, independent of the obvious risks of reduced visual acuity and/or physical mobility. Though this information is useful in potentially identifying the driver at risk, additional information is necessary to determine under what conditions these cognitive risk factors operate. That is, do these cognitive difficulties contribute to risky driving under any condition, or are they most salient in specific situations or for specific maneuvers?

To date, the studies with nonclinical populations have used crash data (either self-reported or state records) as the outcome of risk. The current study was undertaken to extend our research of crash risk to actual driving performance on the road with a community-based, nonreferred sample of older drivers. This study represents an initial attempt at determining which driving behaviors and situations are most problematic for older persons with respect to cognitive risk factors. We hypothesized that (a) higher volume traffic interactions (e.g., highway merging and intersection negotiations), (b) speed regulation and distance estimation, and (c) vehicle positioning would be significantly related to visual attention and spatial abilities.

Methods

Participants

Study participants were 35 driving individuals identified from the Project Safety cohort, a probability sample of noninstitutionalized persons aged 72 years and older living in New Haven, Connecticut, in 1989 (15). Project Safety studied the risk factors for falls and fall-related injuries in an older community-living population. The sampling technique for this cohort was similar to that used to establish the New Haven Established Populations for Epidemiologic Studies of the Elderly (EPESE) cohort. Both sampling techniques have been described in detail elsewhere (16–18). Eligibility criteria included the ability to speak English, Spanish, or Italian; to follow simple commands; and to walk across a room without human assistance. Of 1392 eligible persons, 1103 (79%) agreed to participate and were enrolled in the cohort. At the 1-year follow-up interview, there were 915 respondents, of which 283 reported driving in the period between the baseline and follow-up interviews.

Members of the cohort who were known drivers were contacted in 1994 and recruited to participate in a larger study on driving history and sensory (vision), physical, and cognitive function. At that time, there were 161 drivers in the cohort (all of whom spoke English) who were still living, among whom 125 still drove and agreed to an in-person interview. The current study sample consisted of 35 of these individuals who also agreed to participate in a performance evaluation of their driving abilities.

Assessments

Cognitive measures.—Tests used in the cognitive evaluation included both standard clinical as well as experimental tests. They were chosen on the basis of prior research suggesting an association with driving or higher order activities of daily living (6,19). The battery was administered by trained interviewers, and included the Wechsler Memory Scale-Revised (WMS-R) (20) Logical Memory (verbal memory) and Visual Reproduction (visual memory) subtests, Hooper Visual Organization Test (HVOT) (visuospatial cognition) (21), number cancellation task (visual attention) (22), Trail Making Test Part B (executive function) (23), Symbol-Digit Modalities test (24), and experimental measures of simple, choice, and complex reaction times.

Driving performance.—An on-road driving test was developed and standardized for this study. To ensure concurrent validity with the requirements for successful on-road driving in the State of Connecticut (where this study took place), the driving test was taken from the relicensing exam used by the Connecticut Department of Motor Vehicles (DMV) for any individual who is referred for examination due to medical reasons. All 36 items were the same, but the scoring was changed from pass–fail to a 3-point system, ranging from major errors/unsafe (0 points) to minor errors (1 point) to good/no errors (2 points). Standardized scoring criteria were developed for each item before initiation of the study. The evaluation consisted of making parking lot maneuvers and driving on suburban roads, in urban downtown traffic, and on limited-access highways. The road course was 20 miles long and took approximately 45–60 minutes to complete. All road tests were conducted on a weekday at the same time of day using the same dual-brake-equipped vehicle for all participants. Sessions were rescheduled during inclement weather. A single experienced driving therapist who was not aware of the participant's performance on the cognitive test battery evaluated each participant's driving skills during the course of the road test using the 36-item scale.

Internal consistency of the scale is high (coefficient alpha = .88). Interrater reliability was assessed on 357 separate older drivers. Two driving evaluators, each alternating their roles as the designated examiner in the front seat or observer in the back seat, rode with each participant and provided independent ratings on the 36-item scale. Interrater reliabilities were quite high for the scale, as indicated by the intraclass correlation coefficient of .99 for the total score. Weighted kappas for each of the 36 items on the scale were also computed, the majority of which were greater than .91 (n = 26, range .911–.998). The remaining items yielded kappas in acceptable ranges (>.80). Therefore, the overall score is based on 36 items with a maximum total performance score of 72.

Data Analyses.—Partial correlations were computed between summary cognitive test variables and overall score on the road test, controlling for any demographic or noncognitive risk variables that correlated with the cognitive tests. For those cognitive tests showing a significant partial correlation with the road test score, individual item correlations were computed between each cognitive test and each of the 36 individual road test maneuvers or driving situations, again controlling for any variables that correlated with the cognitive tests.

Results

Demographic Characteristics and Driving Patterns

Table 1 provides baseline characteristics of the study sample compared with current drivers in the cohort who did not undergo the road test ($n = 90$). Participants had a mean age of 80.2 years ($SD = 3.0$), mean education of 11.9 years

Table 1. Characteristics of the On-Road Driving Participants Compared With the Nonparticipants From the Overall Driving Cohort

	On-Road Sample (n = 35) Mean (*SD*)	Nonparticipating Drivers (n = 90) Mean (*SD*)
Age (y)*	80.2 (3.0)	81.9 (3.3)
Education (y)**	11.9 (3.0)	10.4 (3.8)
Male (%)	68.6	52.2
White (%)	85.7	90.0
MMSE score (max. 30)**	27.6 (2.2)	26.2 (3.2)
Number driving days/week (%)		
Daily	61.8	53.3
Every other day	26.5	31.1
1–2 times/week	11.8	14.4
1–2 times/month	0	1.1
Estimated weekly mileage	83.6 (58.4)	75.5 (83.8)
% Reporting crashes/moving violations in preceding 5 years**	57.1	33.3

Notes: $*p < .01$; $**p < .05$.
MMSE = Mini-Mental State Examination; *SD* = standard deviation.

(*SD* = 3.0), and the majority of participants were male (68.6%) and white (85.7%). On the Mini-Mental State Examination (MMSE) (25), a brief screen of general cognitive status, the participants' scores ranged from 19 to 30 with a mean score of 27.6 (*SD* = 2.2). As noted, all participants were living independently and reported being active drivers. The relatively high average MMSE score reflects the independent living status of these individuals, though as can be seen by the range of scores, these drivers were not preselected for being free from cognitive impairment.

Participants reported varying patterns of driving, with the majority driving at least 4 days a week (88%). Estimated weekly mileage driven varied widely, ranging from 4 to 248 miles (mean weekly mileage = 83.6 miles, *SD* = 58.4).

When compared with the overall driving cohort from whom these participants were recruited, the sample as a group was slightly younger (80.2 vs 81.9 years, $p < .01$), more educated (11.9 vs 10.4 years, $p < .05$), with slightly higher MMSE total scores (27.6 vs 26.2, $p < .05$). The sample did not differ on other demographics or on relevant driving variables, such as frequency and amount of driving. Interestingly, they did have a slightly but significantly higher rate of self-reported crashes and/or moving violations in the previous 5 years compared with the overall driving cohort (57% vs 33%, $\chi^2(1) = 5.95$, $p < .05$). Thus, there did not appear to be a self-selection bias for being "safe" drivers.

Cognitive Tests and On-Road Driving

Performance on cognitive tests and the road test are presented in Table 2. The group means on the cognitive tests are within normal ranges when compared with available published norms for standard tests (i.e., HVOT, WMS-R Logical Memory, Visual Reproduction, Symbol Digit, Trails B). The range of performance for the road test score was 14 to 72 (maximum), suggesting that drivers exhibited a full range of skills from exceedingly poor to rather competent.

Table 2. Performance On, and Partial Correlations Between, Cognitive Tests and Road Test Controlling for Distance Vision

	Mean (*SD*)	Partial r With Road Test	Variance (%)
Visual Attention			
Number cancellation	53.7 (19.0)	.43*	18.5
Executive Function			
Trail Making Part B (s)	157.8 (63.4)	–.38*	14
Visuospatial Cognition			
HVOT	20.2 (4.0)	NS	
Memory			
LMI (verbal memory)	18.0 (6.5)	NS	
VRI (visual memory)	24.0 (7.9)	.40*	16
Visuomotor Speed			
Symbol Digit	27.1 (4.0)	NS	
Reaction Time			
Simple	0.8 (0.4)	NS	
Choice	0.7 (0.3)	NS	
Complex	0.9 (0.5)	NS	
Road test total score	63.0 (13.0)	—	

Notes: $*p < .05$.
HVOT = Hooper Visual Organization Test; LMI = Logical Memory I from Wechsler Memory Scale-Revised (WMS-R); VRI = Visual Reproduction I from WMS-R; *SD* = standard deviation; NS = not significant.

Bivariate correlations were first computed between cognitive tests and demographic, physical, and vision variables that might have influenced road test performance. The cognitive tests did not correlate with age or measures of physical function. However, among vision variables, acuity as measured by distance vision was correlated with several cognitive variables (absolute value of r ranged from .37 to .38, $p < .05$). Therefore, distance vision was used as a covariate when correlations were computed between cognitive tests and any road-test variable (i.e., total score and individual items).

Partial correlations (controlling for distance vision) were significant at the $p < .05$ level between driving performance score and cognitive tests of visual attention (number cancellation), visual memory (WMS-R Visual Reproduction), and executive function (Trail Making Test Part B). The remaining cognitive tests, both standard and experimental, did not demonstrate any significant associations with the road test total score ($p > .15$).

To determine which maneuvers and situations were related to the cognitive abilities, individual item correlations between driving behaviors and the 3 cognitive tests (again, controlling for distance vision) were computed (Table 3). Visual attention was associated with 25 of 36 driving items (17 at the $p < .05$ level and 8 at the $p < .01$ level). These included scanning the environment (e.g., scanning from side to side), interaction with traffic and/or pedestrians (e.g., yielding right of way, responding to other vehicles or pedestrians, using directional signals, making turns in an intersection), and monitoring speed and judging distances appropriately (e.g., gas-to-brake response time, following at a safe distance). Visual memory was associated with 9 maneuvers at the $p < .05$ level and 7 maneuvers at the $p < .01$ level, and executive function was related to 10 maneuvers at the $p < .05$ level and 7 maneuvers at the $p < .01$ level. Most of these maneuvers overlapped with

Table 3. Partial Correlations Between Road Test Items and Cognitive Tests After Controlling for Distance Vision

Road Test Item	Visual Attention (Number Cancellation)	Visual Memory (Visual Reproduction I)	Executive Function (Trail Making Test Part B)
1: Scans to sides	.38*	.44*	−.40*
2: Scan to rear/head check			
3: Uses mirrors			
4: Uses seatbelt			
5: Responds to traffic signals	.35*		−.35*
6: Responds to vehicles/ pedestrians	.53**	.59**	−.50**
7: Grants right of way	.48**	.47**	−.34*
8: Centers car in lane	.37*	.36*	
9: Safe following distance	.42*	.40*	
10: Uses directional signals	.41*		
11: Positions car for turns	.44**	.52**	−.34*
12: Proper lane selection	.34*		
13: Gas-to-brake reaction time	.34*		−.40*
14: Appropriate steering recovery	.39*		−.39*
15: Acceleration			
16: Braking	.42*		
17: Shifting			
18: Right turns			
19: Left turns	.42*	.43*	−.38*
20: Backing up			
21: K turns			
22: Angle parking			
23: Low density traffic	.48**	.39*	−.36*
24: Simple traffic situations	.50**	.45**	−.44**
25: Medium traffic situations	.50**	.45**	−.44**
26: Limited access highway	.41*		
27: Enter		.45*	−.48**
28: Exit	.39*		
29: Merge	.42*	.46**	−.48**
30: Lane change	.42*		−.73**
31: Speed regulation	.43*		
32: Follows directions	.36*	.36*	
33: Judgment	.58**	.42*	−.39*
34: Decision making	.46**	.44*	−.48**
35: Memory			
36: Attitudes and Emotions	.40*	.48**	−.40*
Partial *r* with Road Test Total	.43*	.40*	−.38*

Notes: $*p < .05$; $**p < .01$.

visual attention, but others involved judgment situations (e.g., when and at what speed to enter onto highways, appropriate timing when making lane changes).

Discussion

The findings of this study are consistent with our longitudinal research indicating a major role for visual attention in driving performance in this sample of older persons (6). Visual attention accounted for 18% of the variance on the road test after controlling for the effects of visual acuity, and it was associated with over half of the specific driving maneuvers required of the participant. Although tests of executive function and visual memory were also associated with overall driving performance, the specific maneuvers related to these cognitive domains in general formed a subset of those that were related to visual attention, with minor exceptions. This overlap is not surprising, particularly given that the measure of executive function (Trail Making Test Part B) requires visual scanning and search.

With respect to driving maneuvers, the results indicate that maneuvers involving interaction with other vehicles/ pedestrians have the greatest association with visual attention. These maneuvers include scanning the visual field for potentially dangerous obstacles, maintaining one's speed and distance with respect to other vehicles, yielding the right of way, and negotiating turns or merges safely. These findings are consistent with the literature on types of crashes in which older persons are more likely to be involved. For example, Ball and colleagues found that 67% of crashes of older drivers occur at intersections compared with only 50% of crashes among younger drivers (26). Importantly, intersections are likely to be the locations where scanning, vigilance to obstacles, and yielding right of way are important driving maneuvers that dictate one's degree of safety. In fact, statistics from the National Highway Traffic Safety Administration (NHTSA) indicate that the proportion of older drivers involved in crashes having a ''right of way'' or a traffic signal violation is three times greater than for all other ages combined (27).

Some limitations of the current study bear discussion. The primary limitation is the small sample size, and therefore, conclusions presented here must be viewed as preliminary. With larger sample sizes, other cognitive variables may emerge as being important for the execution of common driving maneuvers.

Additionally, these data reflect the association between driving skills and cognition among nonclinic-referred individuals. Individuals who have known or preidentified cognitive impairment (e.g., Alzheimer's disease) may exhibit different patterns of associations between driving and cognitive tests. In a number of studies examining driving performance (either simulated, closed-course, or open-course performance) in cognitively impaired samples (mild dementias or Alzheimer's disease), dementia severity or global cognitive scales appeared to correlate best with driving (13,14,28,29). The global nature of the deficits in the samples likely contributed to the findings in these studies that all or most of the cognitive tests were also correlated with driving performance. That is, these samples did not allow for demonstrating the specificity of certain cognitive functions in driving performance.

In the present study, it was not our intent to discern the driving and cognition relationship among those preselected for impaired cognition. It was our intent to determine the relationship among specific cognitive functions and driving skills for the typical older driver—someone who lives independently, uses his or her own vehicle as the primary mode of transportation, and does not exhibit obvious cognitive deficits or who has not yet been identified as having cognitive deficits. As such, the current study provides important information regarding the typical older driver, including potential target areas for interventions to enhance driving safety.

Despite the limitations, these data suggest that the identification of both specific cognitive risk factors as well as the identification of problematic driving maneuvers for these individuals at risk may provide guidelines for developing intervention strategies to reduce risk that target visual attention, as well as noncognitive factors such as visual acuity and physical function. Older drivers who are identified as having specific visual attention difficulties may then benefit from educational or training programs designed to increase their vigilance and scanning specifically at intersections, for example. Interventions that would alter driving risk would contribute to the public health and quality of life among many older Americans, and postpone or prevent loss of independence related to driving cessation.

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